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EVALUATION OF A STRADDLE-LIFT VEHICLE
AS A CONTAINER HANDLER/TRANSPORTER
FOR AMPHIBIOUS OPERATIONS

Michael J. Wolfe

Naval Civil Engineering Laboratory
Port Hueneme, California

March 1973

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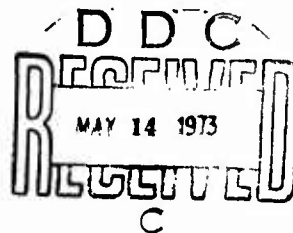
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ABSTRACT

The Landing Craft Retriever Unit (LCRU) at the U. S. Naval Amphibious Base, Coronado, California, was used as a test vehicle to evaluate the straddle lift concept of container handling for amphibious operations. The LCRU was used to load and unload a beached LCM-6 landing craft. The cargo was an 8'x8'x20' maritime van container loaded to 22.4 tons gross. In addition, the LCRU was used to haul the container up various sand slopes and across unimproved terrain, and to load the container onto a trailer.

It was concluded from the tests that an LCRU-type vehicle - i. e., a towed straddle lift - is a stable, fast, and efficient container handler which is well-suited to unloading and loading beached landing craft. It was also concluded that the straddle lift is well-suited to transporting containers over beaches and other unimproved terrain.

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INTRODUCTION

The widespread use of maritime containers by the shipping industry is a subject amply discussed in the literature. The Department of Defense recognizes that the trend to containerization will have a great influence on logistic operations and in turn has endorsed and implemented containerized shipping for military supply. Efforts are currently being directed toward developing techniques and equipment for unloading container ships at advanced bases during contingency operations. Many options are being considered to ensure that military logistics officers can employ all common modes of shipping now and in the future.

Options under consideration include the transfer of containers ship-to-shore via conventional landing craft, primarily LCM-6's, LCU's, and LCM-8's, or pontoon causeways. The operation would consist of bringing the landing craft or causeway alongside the cargo ship to a point where the container could be lowered into the cargo well of the landing craft or onto the deck of the causeway. The craft or causeway would then proceed to the beach where a lifting device could remove the container for transport inland. One of the problems in this system is that none of the materials handling equipment suitable for use in military contingency operations has the capacity to handle a fully-loaded maritime container at the beach/water interface. The experiment reported herein is concerned with solving this problem. It was conducted at the U. S. Naval Amphibious Base at Coronado, California, 27-30 March 1972, with the assistance of Naval Beach Group ONE.

The objectives of the test were to: (1) determine the suitability of a straddle-lift vehicle for container handling at the beach/water interface and (2) obtain data that will help in specifying the design features of a container handler suitable for use in contingency operations. Using the Landing Craft Retriever Unit (LCRU) as a test bed, the specific operations to be studied were: (1) removal of containers from beached landing craft and (2) transport of containers over unimproved terrain.

EQUIPMENT

Landing Craft Retriever Unit (LCRU)

The Landing Craft Retriever Unit is the latest in a family of landing craft retrievers and surf cranes which have evolved over the last thirty years. As shown in Figure 1 and 2, the LCRU is a straddle lift towed by a crawler tractor. It can straddle, lift, and transport

LCM-6 landing craft. Seven of the units are stationed at the Amphibious Base at Coronado, California. Lifting power is supplied by a diesel engine mounted on the LCRU frame. The following technical description outlines the essential features of the unit:

Lifting Capacity:	75 tons - Load may be carried on single center safety hook of 75-tons capacity or two outboard safety hooks of 37.5-tons capacity each on spreader beam. Spreader beam equipped with safety stop.
Load Dimensions:	Maximum Length 61 feet Maximum Width 15 feet Maximum Height 26 feet
Operating Capability:	Crane can operate on 15% grade and 10% tilt.
Hook Height:	Maximum 27 feet.
Hoist Winches:	Two self-contained winches each with integral hydraulic motor and internal automatic safety brake which operates instantly in the event of any power loss. Operating brake effective in both directions on each unit.
Hydraulic System:	Powered by diesel engine with 110-gallon hydraulic fluid reservoir including filter lines. The system has capability for lifting, controlled lowering and holding the load in position. Diesel engine with electric starting and 250-gallon capacity fuel tank.
Load Stabilizers:	Four 5-ton hand operated ratchet type snubbing winches, each with fair-lead and 50 feet wire rope. Winches installed at legs of super-structure. These were not used in the experiment.
Turning Radius:	43 feet with a D-7E tractor.
Operator's Platform:	Located on frame with control console and adjacent to engine platform.

Frame:	Superstructure of flanged tubular construction with ladders and walkways. Rubber bumpers mounted on horizontal frame at all load contact points.
Wheels & Tires:	Wheels interchangeable each side and wheel hubs mounted on tapered roller bearings. Tires are 33.5 x 39 - 38 ply, 75 psi tubeless type. Wheel and tire demountable as an assembly.
Mobility:	Towed by tractor - 5 mph with 40-ton load. - 2 mph with 75-ton load.
Overall Height:	37 feet 9 inches
Overall Width:	27 feet 3 inches
Overall Length: (less tractor)	48 feet 6 inches
Total Gross Weight:	66,500 pounds

Unit disassembles into seven structural components and two wheels. Heaviest component is 18,650 pounds.

Operation of the LCRU is straightforward. Once the landing craft is beached, the LCRU backs over the craft and the lifting beam is lowered. The free ends of the four cables suspended from the center hook are then attached to deck fittings and the craft is lifted. Usually a crew of five is used: four men on the LCRU itself and one driving the tractor. However, if need be, the crew can be reduced to three. The three man crew was used for the container handling experiment.

Tractor

A Caterpillar D-7E tractor was used to tow the LCRU. It is equipped with a standard 5-speed transmission and clutch. Some additional information on the tractor includes:

Horsepower	160
Gauge*	78"
Length overall (without blade) . . .	14'8"
Width overall (without blade) . . .	8'4-7/8"
Weight with blade (approx.)	40,000 lbs
Top Speed	6 mph
Drawbar height	17-13/16"
Grouser height	1-1/2"

* Distance between track centers.



Figure 1. Landing Craft Retriever Unit (LCRU).

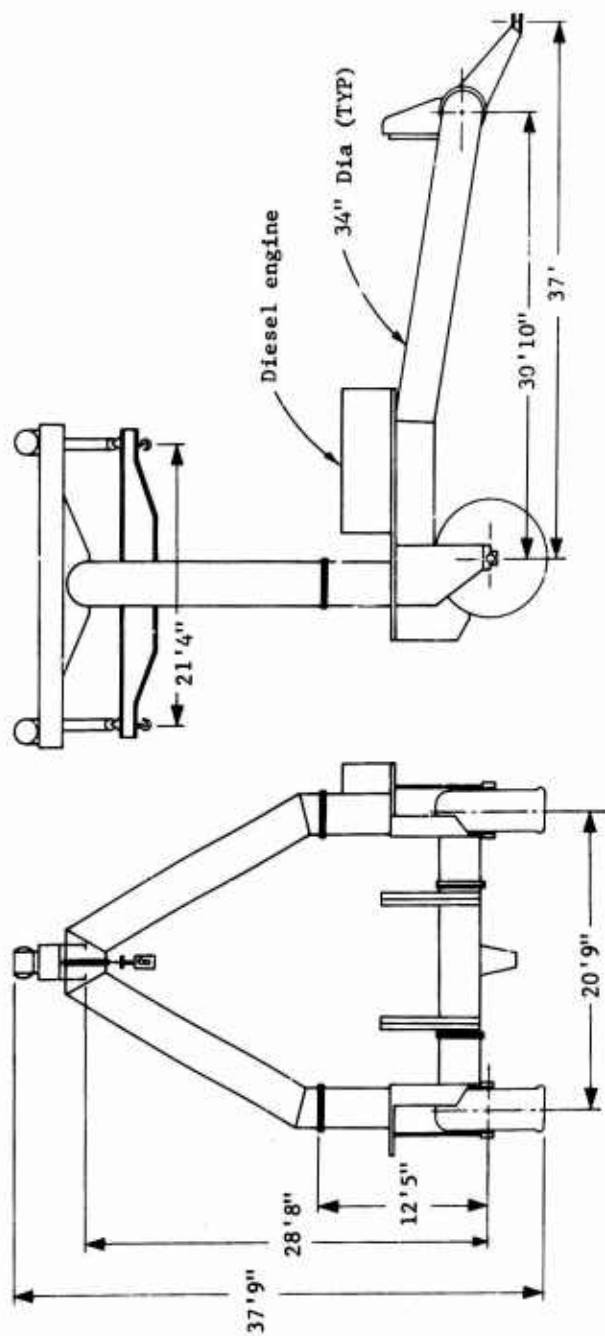


Figure 2. Dimensions of the LCRU.

Landing Craft

An LCM-6 was used in the experiment. Figure 3 presents some dimensions of the craft. To prevent damage to the LCM-6, heavy planks were placed in the well deck to distribute the weight of the heavily-loaded container. Three planks strapped together with lug bolts were placed in the forward part of the craft; an identical set of planks was placed rearward approximately 20 feet. Fenders made from heavy rope were hung on the inside of the cargo well.

Container

A standard 8'x8'x20' maritime container was used as the cargo. It was loaded with concrete bricks to a gross load of 22.4 tons. This is the maximum gross weight allowed for a container of this size.

Spreader Bars

Two simple spreader bars with 7½-ton hooks at each end were fabricated for use in the experiment. The dimensions and features of the spreader bars are shown in Figure 4. A spreader was suspended from the hook at each end of the lifting boom on the LCRU. Figure 5 illustrates how the crew connected the spreader to the container. Figure 6 shows the spreader in use on a LCRU carrying the container; in the background another LCRU can be seen hauling an LCM-6 to the ocean.

TEST PROCEDURE

The test procedure consisted of two phases: (1) using the LCRU as transport equipment hauling the container through the surf and across some rough terrain and (2) using the LCRU to load and unload beached landing craft. Before the test took place, the topography of the beach and characteristics of the sand were measured. Still and motion pictures were taken and observations made and recorded during various phases of the test. Upon completion, the crew was interviewed.

The following sections present the results of the data gathering, observations, and post-test interviews.

TEST EXECUTION, OBSERVATIONS AND DISCUSSION

Spreader Bar and Lifting Arrangement

The tests clearly demonstrated that the lift employing two spreader bars offers some important advantages. First, the container could not rotate, thereby eliminating the need for taglines to prevent such motion. Second, the use of separate bars with hooks allows greater tolerance

when positioning the LCRU over the container. A container spreader bar with commercial twist-locks (such as is used in sea port container operations) would require precise positioning to hook-up with the container. The slings used in the LCRU tests provided the freedom required for the crew to insert the lifting hooks with relative ease, regardless of whether the container was on a tilt or if the LCRU was not backed squarely over the container.

Early in the test a single point lift of a container was attempted. One 8-foot long spreader bar was suspended from the center lift hook of the LCRU lifting beam. The single spreader had two lines attached to each end. A line was passed to each of the lower corner fittings of the container. This single point suspension was unacceptable because it allowed the container to rotate. In order to prevent rotation, the stabilizing lines (mounted on the hand operated winches) of the LCRU were connected to the container. This was a troublesome, time-consuming operation.

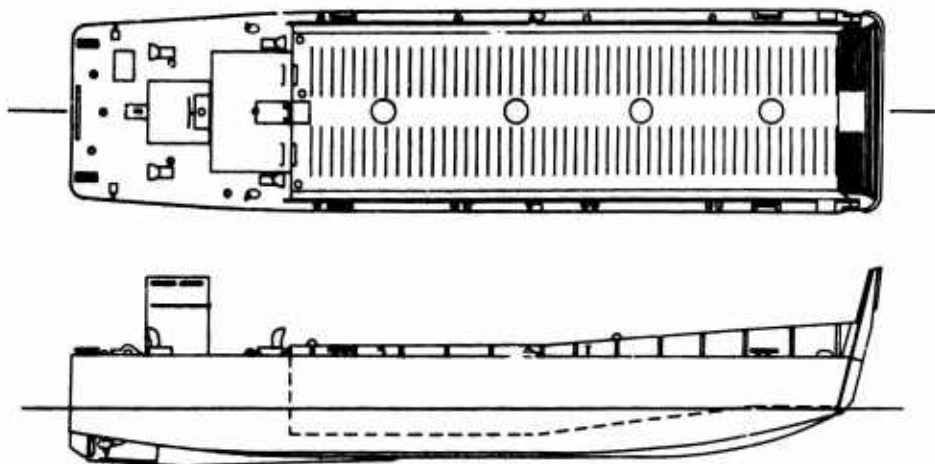
The lifting hooks were relatively easy to manipulate. No unusual effort was required to pass the hook through the top corner fitting of the container. The crew mentioned that even faster hook-up times would be possible using a quick-acting bulb hook. These hooks are designed to be inserted in the side hole of the corner fitting and rotated 90° to lock into position. This type of connection has been successfully used in other container handling operations.

Container Transport with the LCRU - Container Motion

Figures 7 and 8 illustrate how the container was suspended and the clearances between the container and framework of the LCRU. The lifting beam of the LCRU must be raised completely to the top of the "A" frame before the unit can move. The lifting beam is locked at the top to prevent it from pitching, yawing, and surging. Thus, the container is essentially suspended from a fixed beam, and only lateral and/or transverse movements are possible.

During transit along the beach the swinging motions of the untethered container were not great enough to cause concern. The clearances between sides of the container and the LCRU were large enough to allow the container to swing freely without hitting the LCRU. Travel speeds ranged from two miles per hour over the roughest terrain to approximately six miles per hour (the maximum speed of the D-7E tractor) at the water's edge.

Swing motions forward and aft were occasionally of large magnitude. But, as shown in Figure 8, the clearance between the forward end of the container and the front cross member of the LCRU is great enough to make it highly unlikely that the container could swing fore-to-aft to strike anything.



Purpose	To land cargo and personnel during amphibious operations
Capacity	68,000 pounds
Length overall	56'11"
Beam	14'4" maximum
Draft	3'10" loaded
Full load displacement	124,000 pounds
Hoisting weight	56,000 pounds
Speed	9 knots at full load displacement*
Fuel capacity	450 gallons
Range	130 nautical miles at full power and full load
Cargo well	Approximate dimensions: 37'6" long, 11'0" wide, 6'3" deep

* Loaded with a 20-ton container, the LCM-6 can travel at approximately 12 knots.

Figure 3. Dimensions of the LCM-6.

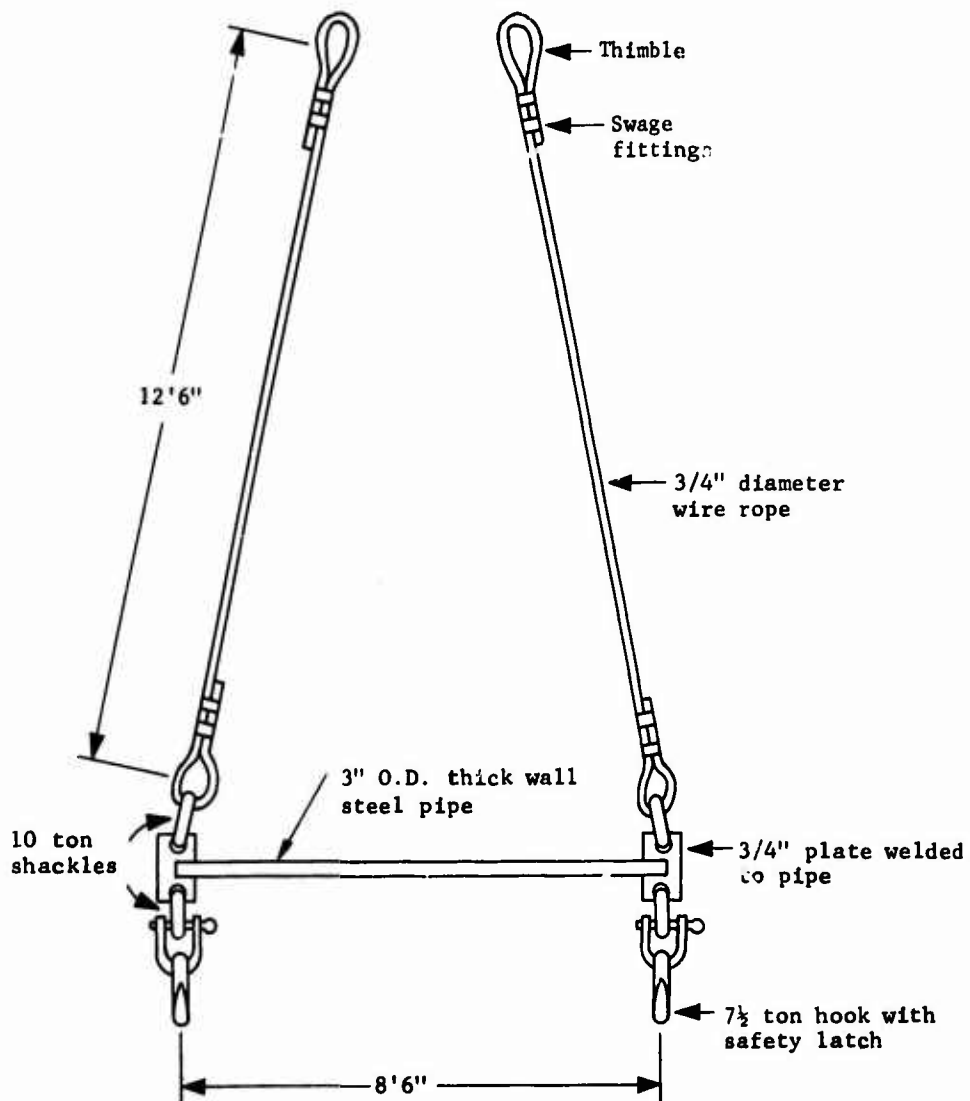


Figure 4. Spreader bar used in the tests.

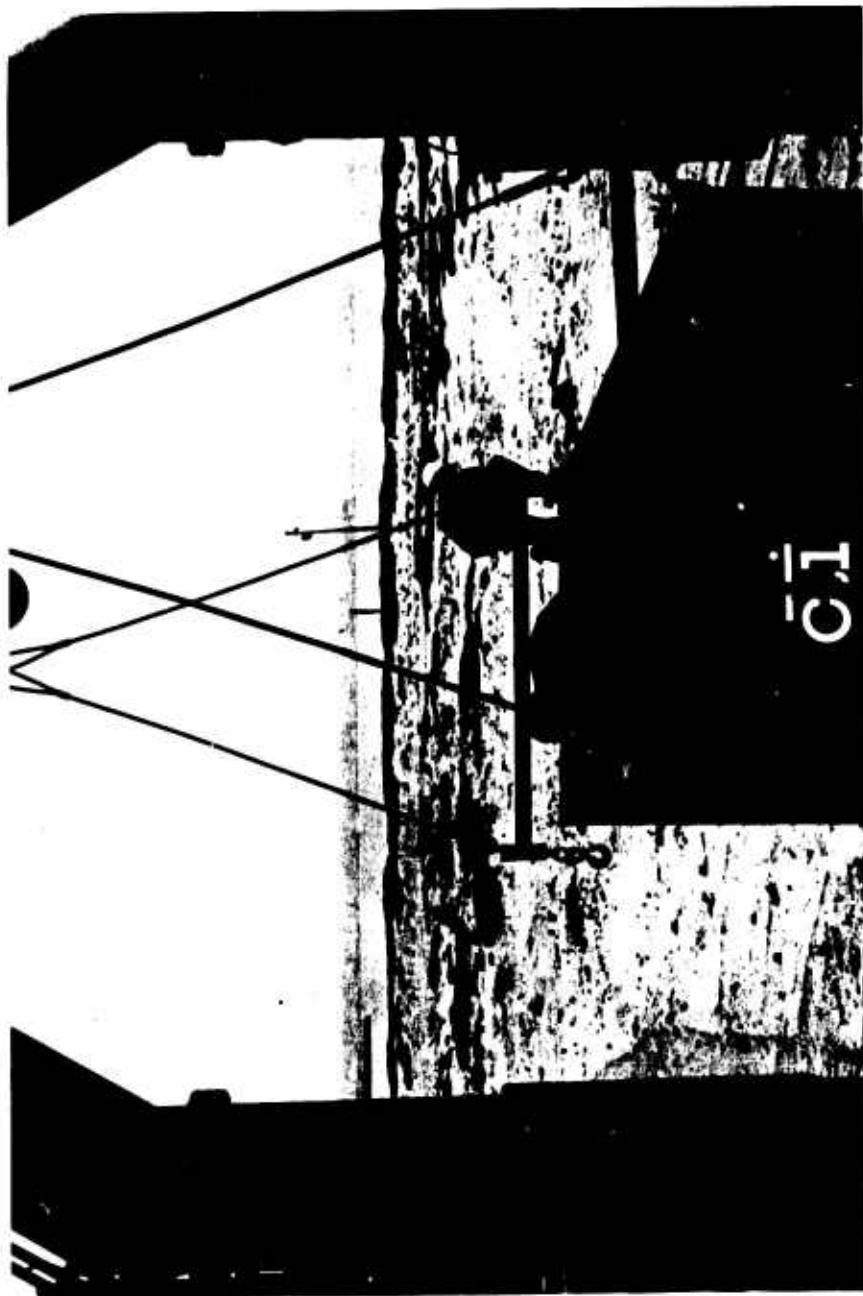


Figure 5. LCRU crew connecting spreader bars to a container on the ground.

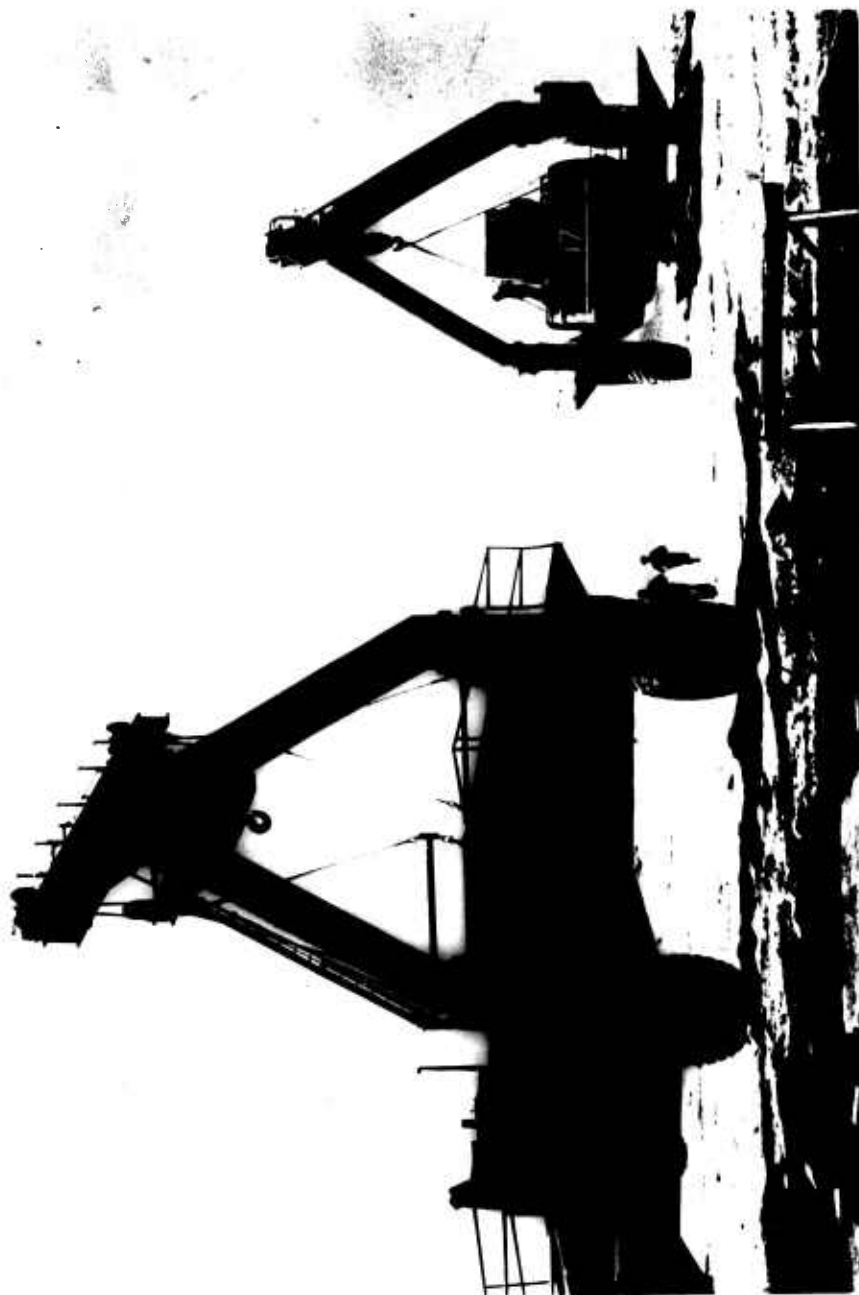


Figure 6. LCRU carrying container and LCRU carrying a LCM-6. Note that to carry the LCM-6, the center hook is used.

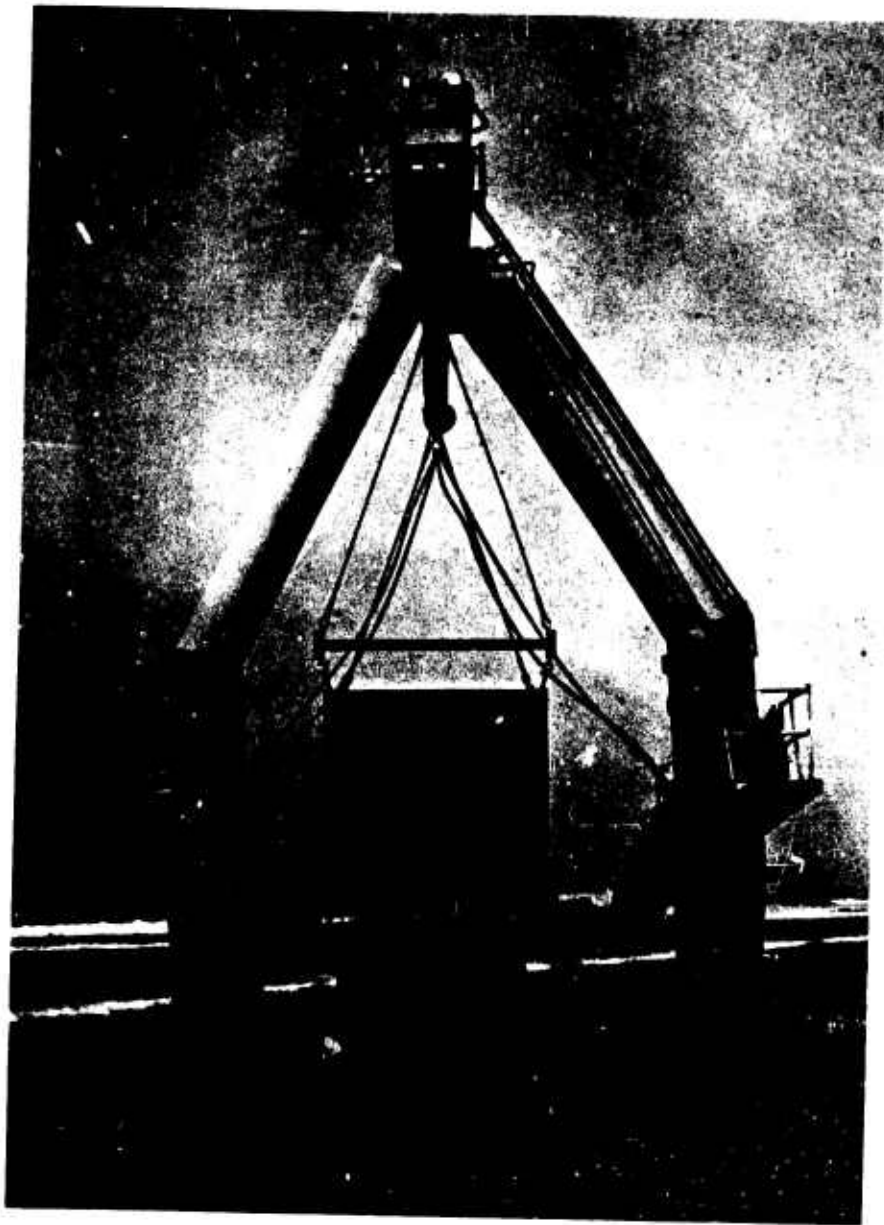


Figure 7. View of the LCRU with container from the rear. The LCM-6 lifting lines are secured to the legs of the LCRU.

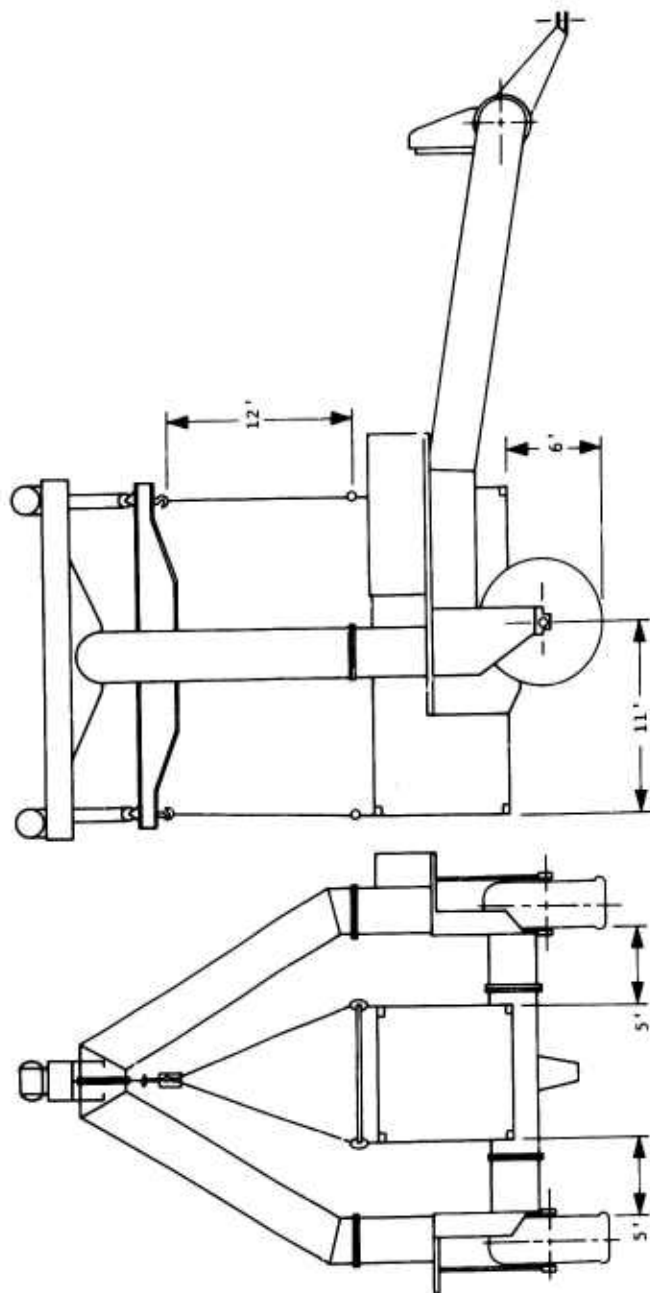


Figure 8. Critical dimensions of the clearances between the container and the LCRU.

Dry Land Loading the Container in the LCM-6

The container was first placed in the LCM-6 while the latter was resting on dry land. Figure 9 shows the results of this operation. Backing the container into the landing craft was as simple and fast as backing the LCRU over the landing craft (which, of course, was essentially all that was occurring).

The slings supporting the spreader bar were too long to allow placement of the container into the landing craft with its bow ramp up. If it is considered desirable to do so, slings could be designed to allow the container to clear a raised bow ramp. However, this appears unnecessary, since raising and lowering the bow ramp is normal operating procedure for landing craft and requires no undue effort or time to accomplish. Also, having long slings will place the container closer to the ground and thereby provide for a more stable vehicle during transport.

Container Transport with the LCRU - Mobility

The LCRU loaded with the container was towed along the beach, up the beach face (and berm), and over a relatively flat but irregular sandy area covered with small patches of ice plant and other common sand binders.

Some sizeable dunes of loose sand had been built-up over this flat area that has also been the site of many heavy equipment operations. As a consequence, there were some deep ruts and large obstructions over which the LCRU could be towed.

Three measurements were made in conjunction with the mobility tests: (1) beach topography, (2) soil characteristics, and (3) drawbar pull.

Beach Topography. The beach profile was measured with standard surveying instruments. The profile is shown in Figure 10. The slope of the beach was approximately 12%. The crest of the berm was slightly over seven feet above mean high tide. The beach slope seaward from mean high tide was approximately 7% to a point well beyond the point where the landing craft beached. Inland, the beach was reasonably flat with the mounds and ruts mentioned above.

Soil Characteristics. Soil samples were taken from selected areas of the beach. Soil density and moisture were measured in situ with nuclear densiometer. Sieve analyses were performed on the samples. The results of the soil analysis are presented in Appendix A. The values for soil density and moisture content suggest there is nothing out of the ordinary as far as these factors are concerned. The sieve analysis also gave "typical" results, although the sand at the test site at Coronado may be slightly finer than is commonly found on the Atlantic coast. All things considered, the beach composition does not differ significantly from any other beach sand. It can be assumed, therefore, that the performance of the LCRU at Coronado is representative and that the unit would perform similarly at any beach.

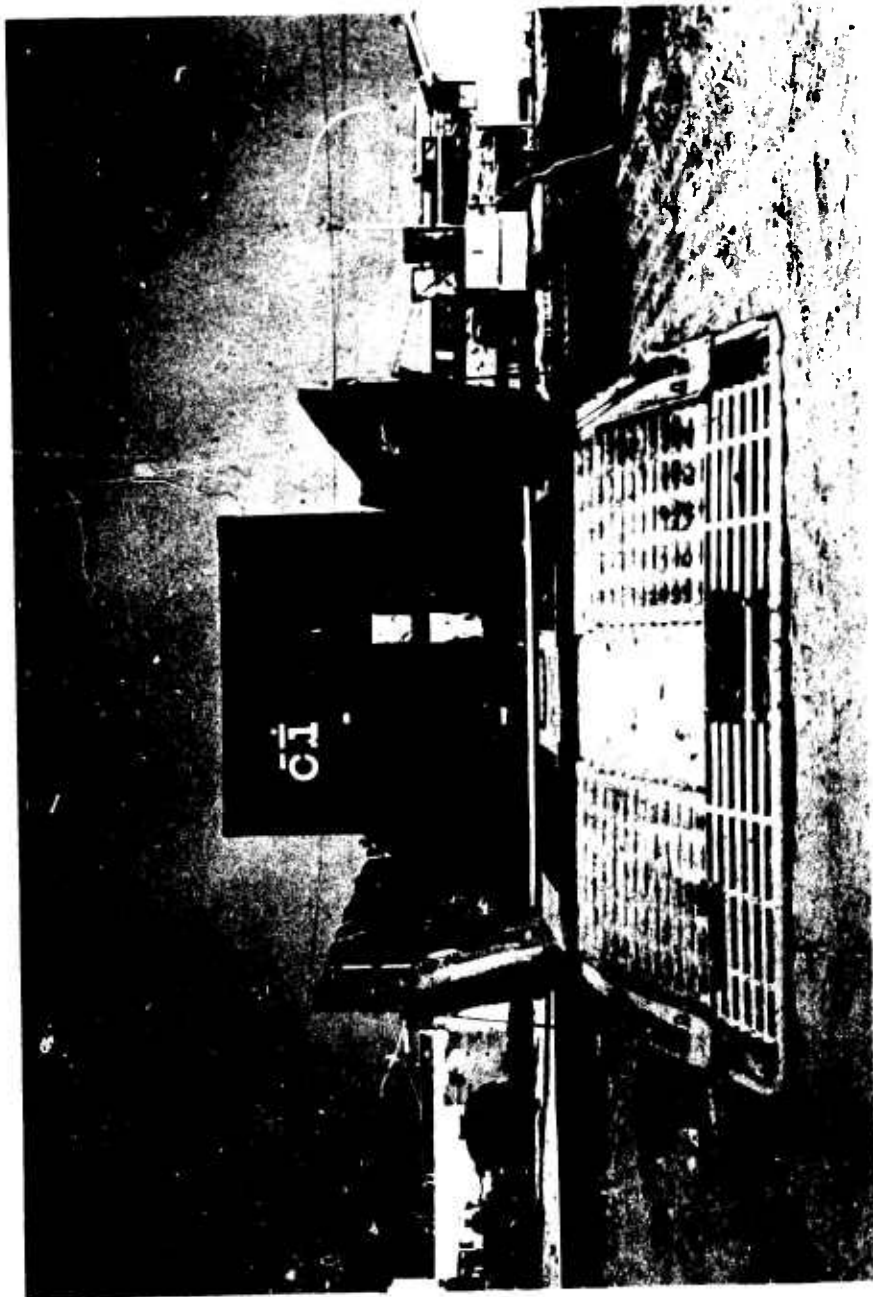


Figure 9. End view of the dry-land placement of the container in the LCM-6

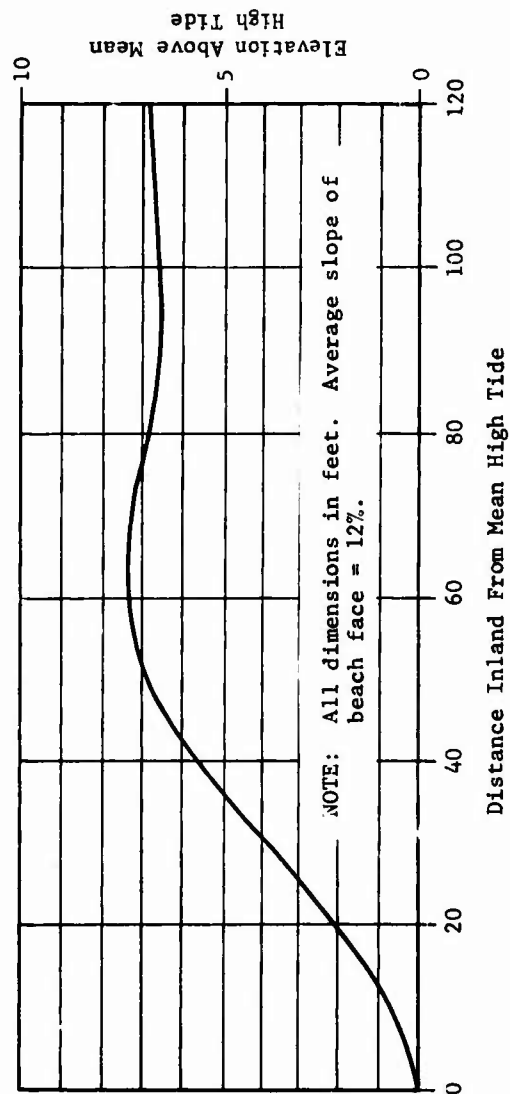


Figure 10. Beach profile at test site.

Drawbar Pull. The link between the D-7E tractor and LCRU is shown in Figure 11. Strain gages were placed on the top and bottom of the link and calibrated from 0 to 29,000 pounds. The calibration was accomplished by pulling one tractor against another with a direct read scale between them. The 29,000 pound figure was reached when the tractor without the link began to slide across the sand.

In general, the LCRU loaded with the container was towed easily by the D-7E tractor. The unit was towed in up to 6 feet of water. It ascended the 12% slope of the beach (in third or sometimes fourth gear) and traversed the irregular surfaces of the inland area. All operations were performed with ease.

The drawbar pulls for various situations are given in Figure 12. The smallest forces were required to tow the unit along flat, hard, wet sand at a top speed of approximately 6 miles per hour. Drawbar pulls in the neighborhood of 4,000 pounds were required to pull the LCRU plus container along the beach.

Larger drawbar pulls were required to pull the unit up the berm and through loose, flat sand. It can be seen in Figure 12 that the largest drawbar pull measured towing the unloaded LCRU was 16,000 pounds, which occurred when the unit was traversing some one-foot high mounds.

The addition of the 22.4-ton container increased the drawbar pull requirements significantly, since it made the gross load of the LCRU plus container approximately 55 tons. Going up the berm and traversing the hilly area required drawbar pulls in the range of 16 - 28,000 pounds. It can be seen in the figure that some comparatively large forces were required to pull the LCRU over the mounds. Also, when the sand was particularly soft, a drawbar pull on the order of 28,000 pounds was required.

On one occasion the LCRU encountered an obstruction which required special maneuvering to overcome. When crossing a trench about six feet wide and two feet deep at low speed, the D-7E could not pull the loaded LCRU directly out of the trench. The measured drawbar pull during the attempts to free the LCRU was greater than maximum calibrated (probably due to dynamic effects). To free the vehicle, the operator turned the tractor slightly and proceeded forward, causing the LCRU to pivot on one wheel as the other wheel was pulled up and out of the trench.

Surf Operations - Loading the LCM-6

The LCRU was used to place the 22.4-ton container into a beached LCM-6, as shown in Figure 13. In the loading sequence, the crew operated the LCRU in the same manner as picking up a beached landing craft. The LCRU was lined up with the landing craft and backed toward it. Two crew members on the LCRU - one on each corner closest to the tractor - gave hand signals to the tractor operator as the unit approached the landing craft. This technique is simple and successful. In fact, not once during the surf tests was it necessary for the tractor operator to pull forward and re-position the LCRU for another backing attempt.



Figure 11. Tow link between the D-7E tractor and the LCRU.

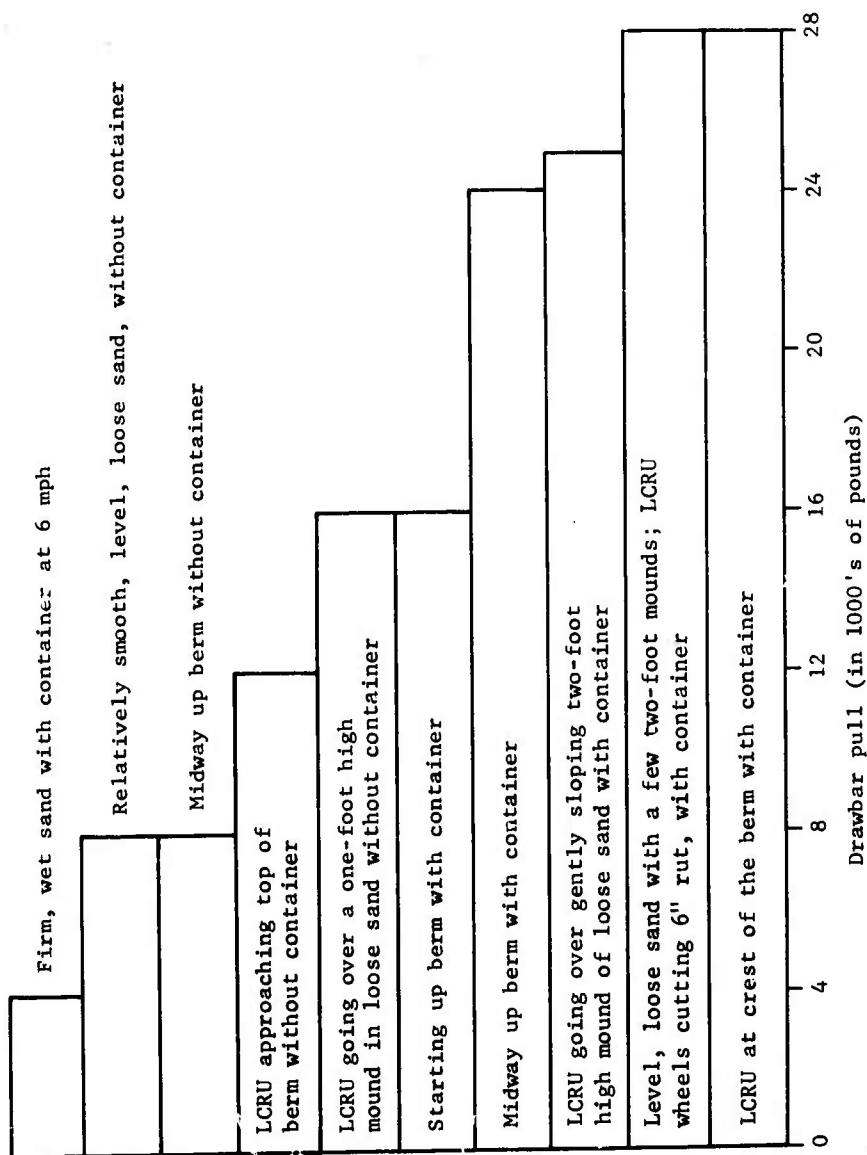


Figure 12. Towing forces.



Figure 13. View of the LCRU straddling the LCM-6 during loading operations.

The first time the container was placed in the landing craft it was approximately 8 feet from the hinge of the bow ramp. It was discovered that this position was too far forward since the large weight of the container pressed the front half of the LCM-6 to the sand. The resulting large contact area between the LCM-6 and sand made it virtually impossible for the craft to free itself. After a few minutes of attempting to free the landing craft by pushing with a tractor, the crew lowered the bow ramp and the LCRU returned to move the container as far to the rear of the cargo well as possible.

Figure 14 illustrates where the container was placed in the landing craft the second time. After placing the container to the rear, the LCRU moved forward a few feet to clear the bow ramp as it was being raised. Then, the LCRU backed up and pushed against the closed bow ramp, as shown in Figure 15, thereby shoving the LCM-6 seaward to deeper water. Even with low tide, the LCM-6 was pushed seaward only 15 feet or so before it had enough water to float.

Surf Operations - Unloading the LCM-6

The loaded LCM-6 returned to the shore and beached. Figure 16 is a photograph of the craft as it approached the beach. Since its loaded draft is greater the LCM-6 beached in slightly deeper water, in contrast to its light condition for the container loading operation. The bow ramp was lowered, the LCRU backed over the craft, and the spreader bars were lowered and attached to the container.

As soon as the container was lifted and supported entirely by the LCRU, the landing craft became more buoyant, although the bow and ramp were still touching bottom. The increase in buoyancy made the landing craft susceptible to the forces of incoming waves. To prevent the waves from pushing the craft forward into the container and/or LCRU, the coxswain gave occasional bursts of reverse power with one engine to maintain position until the LCRU moved the container clear of the bow ramp. The coxswain later stated that this maneuver required no special skill and that anyone familiar with the operation of an LCM-6 would be capable of safely maneuvering the craft.

Surf Operations - LCM-6 Performance

The container simply rested on the cargo well; it was not secured with taglines nor were chock blocks used. This arrangement was satisfactory, and it appears unnecessary to secure containers and other low-profile loads to the landing craft in ship-to-shore operations.

The surf was 2½ feet high on the average with maximum wave heights of 5 feet. The loaded landing craft negotiated the surf with no difficulties in either direction. When going seaward, the coxswain backed the craft to just beyond the surf line and then turned the craft seaward before proceeding further out to sea. When coming ashore the craft was piloted directly at the beach. Whether coming in or going out, the

coxswain stated the craft handled about the same as an empty craft. In fact, he feels that a loaded craft may be even slightly easier to handle in most surf since the weight adds stability. Joint COMPHIBLANT/COMPHIB-PAC operating instructions specify that for an LCM-6 in good condition used in routine exercises, the maximum effective surf limit is 8 feet.

Elapsed Times - Loading and Unloading the LCM-6

The tests were not intended to be an evaluation of the loading or unloading times of the LCRU. Some elapsed times were recorded in the surf tests; they at least suggest the order of magnitude of the (un)loading time involved. It is likely that these times are longer than what could be achieved in a sustained operation with equipment designed specifically for handling containers.

Perhaps the most realistic measure of the speed of the operation is to consider only the time the LCRU spends at the beached landing craft. This eliminates the highly variable factors of travel distance between the LCRU and the beaching point and travel distance from the craft to where the container is deposited. The times required to travel these distances can easily be calculated if the speed of the tow vehicle is known. Re-emphasizing that the test was experimental and not to be construed as anything more than representative, the elapsed times are as follows:

<u>Loading the LCM-6</u>	<u>Elapsed Time (min:sec)</u>	<u>Difference (min:sec)</u>
1. Container over lowered bow ramp	0:0	---
2. Container positioned at rear of LCM-6	0:15	0:15
3. Container sitting on well deck	1:00	0:45
4. Spreader bars released	1:30	0:30
5. LCRU clear of LCM-6	2:00	0:30
Total loading time	2:00	
<u>Unloading the LCM-6</u>		
1. LCRU straddling lowered bow ramp	0:00	---
2. LCRU over the container	0:15	0:15
3. Spreader bars lowered	1:00	0:45
4. Spreader bars attached & container lifted	2:30	1:30
5. Container clear of LCM-6	3:00	0:30
Total unloading time	3:00	

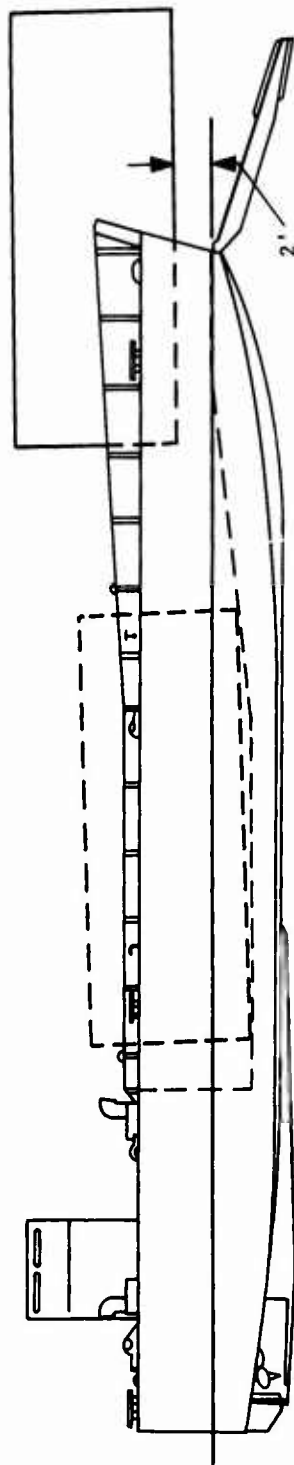
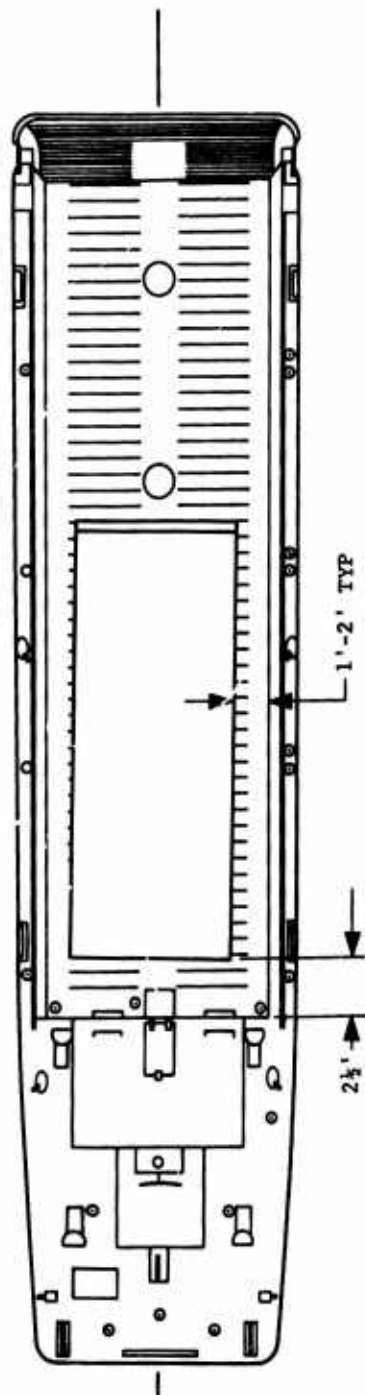


Figure 14. Clearances when the container is in transport mode and during unloading.

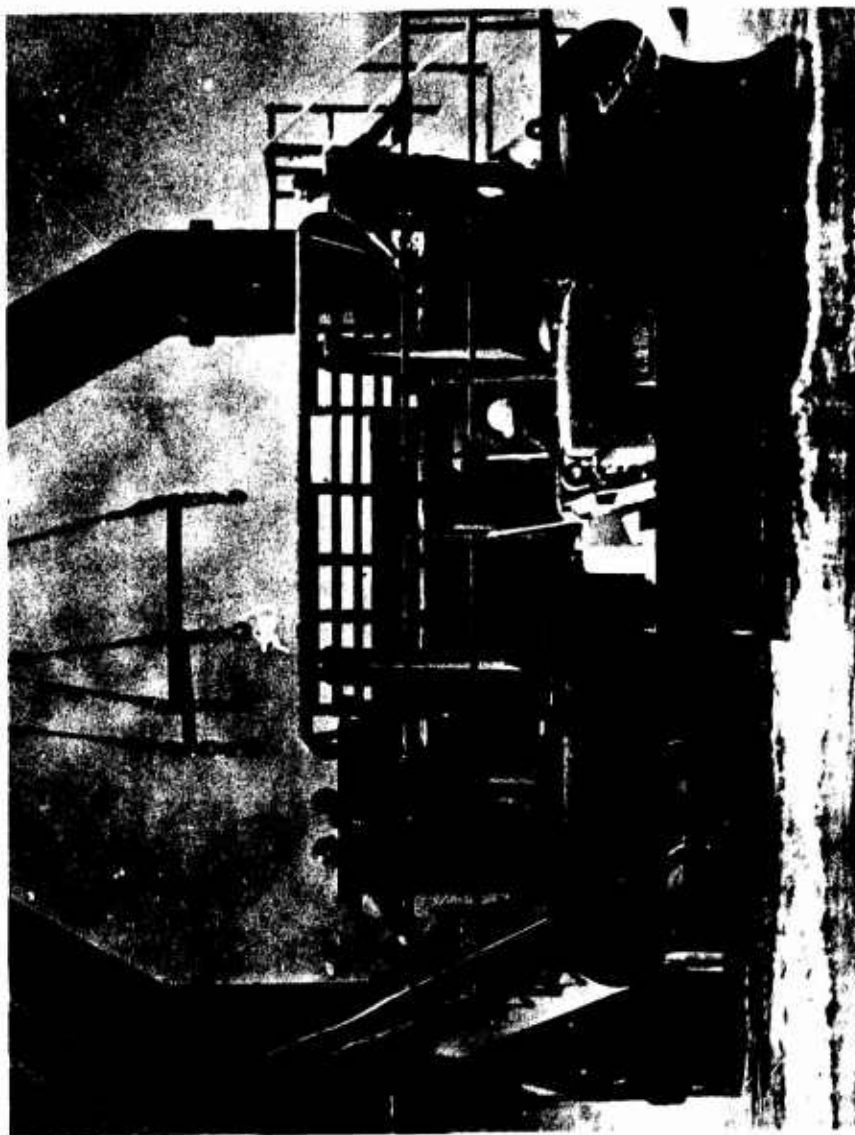


Figure 15. LCRU during pushing operation, shoving the LCM-6 seaward.

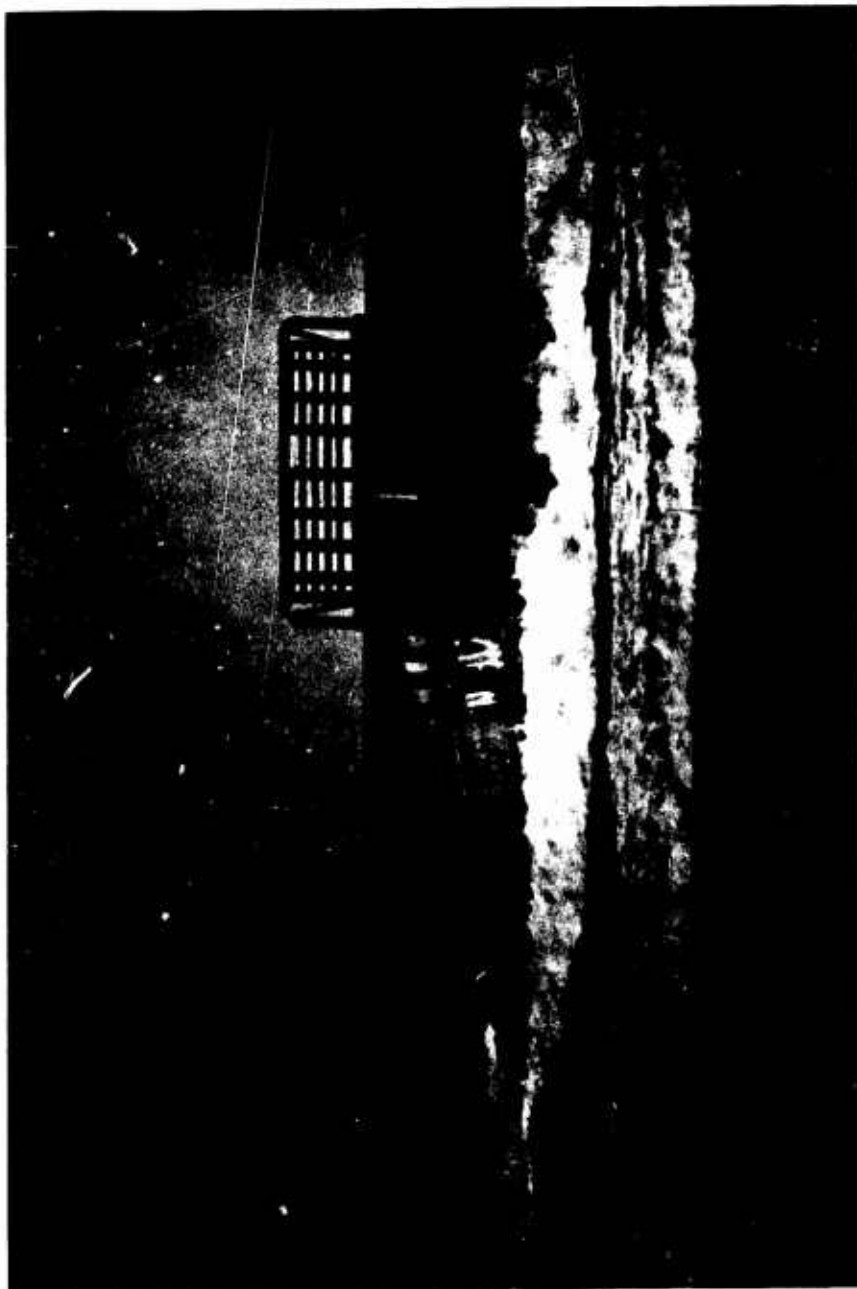


Figure 16. Loaded LCM-6 as it approached the beach for unloading.

The loading time should be increased approximately one-minute if the times to raise the bow ramp (40 seconds) and push the craft seaward (15 seconds) are considered. This does not appear to be a representative operation, however, since it is unlikely that 22.4-ton containers would be loaded into beached landing craft; instead, it appears more likely that empty containers, which weigh approximately two tons, would be placed in beached craft for retrograde. It was the opinion of the coxswain that weights of two tons or less would not prevent the craft from freeing itself in all but the lowest tides. Moreover, since it is more than likely the craft came in loaded, it will be in relatively deep water when it is loaded, i. e., water deep enough to allow the craft to free itself with the relatively light, empty containers.

The elapsed time the LCRU spent at the LCM-6 is longer for the unloading operation (hooking to the container) for two reasons. First, the spreader bars must be pushed into position by the crew. Usually the two men connected one spreader bar at a time: one holding it in position, the other passing the hook through the container corner fittings. In loading, the hooks are simply disconnected and allowed to swing free. Second, when taking the container out of the craft during unloading, the LCRU proceeded more slowly since the increased buoyancy of the LCM-6 (discussed earlier) made the craft more lively and the crew proceeded cautiously until most of the container was clear of the bow.

Also measured was the time to place the container on the ground. An average elapsed time of 1½ minutes was measured - time beginning when the LCRU came to a stop, ending when the LCRU was clear of the container.

The representative times given above could be reduced with two changes to the equipment which could be instituted either singly or together. First, four men instead of two could be employed to hook up the spreader bars. Second, a quick-acting hook could be used. Considering the elapsed times of operation of the system as it stands now, however, it does not appear that either of these improvements are absolutely necessary.

Elapsed Time - Loading a Truck

At the end of the test, the LCRU placed the container on an M-127 semi-trailer towed by a M-52A truck tractor. Figure 17 is a photograph of the loading operation. This was a straightforward maneuver which took approximately four minutes, which included one repositioning of the LCRU due to tight quarters on one side.

It appears possible to reduce the truck loading time considerably by spotting the truck and having guide lines for the LCRU to back between. A large reduction appears especially likely in light of the elapsed times of the LCM-6 (un)loading operations.



Figure 17. LCRU placing the container on a M127 trailer attached to a M52A truck tractor.

POST-TEST INTERVIEWS

After the test, the crew was asked to comment on the container handling operations. They stated that generally no exceptional skill is required to operate any of the equipment used in the tests, but experience with the equipment is a prerequisite. They stated that a three man crew is the minimum required to operate the LCRU in container handling operations with landing craft: one to operate the tractor and two on the LCRU. The crew did not consider the operation particularly hazardous or difficult. The most dangerous aspect of the operation appears to be stepping from the LCRU to the container top during (un)loading operations.

The crew further stated that the LCRU and D-7E are reliable items of equipment which seldom require more than routine maintenance. The tractor operator mentioned that one change he would advocate is the use of a crawler tractor with a power shift transmission rather than the conventional gear box and clutch drive train in the test tractor. The power shift, he feels, would allow smoother and faster gear changes, which is particularly important when down-shifting while going uphill.

CONCLUSIONS

1. The LCRU demonstrated that a straddle lift is a feasible and practical approach to removing van containers from beached landing craft. One of the biggest factors contributing to straddle lift's success is its stability while on the soft footing of the beach and in the surf. Unlike a forklift or boom crane, the straddle lift is not subjected to a tipping moment since the load is centered over the wheels. This is a distinct advantage during loading, unloading, and transport operations.

2. The LCRU (or similar straddle lift) can remove a container from a beached landing craft in no more than 3 minutes (time beginning when the unit first straddles the bow ramp; time ending when the container is clear of the landing craft). The loading time is about one minute less.

3. The straddle lift configuration provides a stable container transport vehicle for use over relatively rough terrain. This is particularly true if a two-point suspension is used.

4. No unusual skill or talent is required to operate the equipment. Moreover, the tasks involved in the operation are not particularly hazardous or taxing for the personnel.

5. The LCRU/D-7E (or similar straddle lift) possess a high degree of mobility. Straddle lifts can meet all the mobility requirements usually desired in a rough terrain transport and handling equipment. Required towing forces, even for the relatively heavy LCRU, are within the capacities of medium size tractors.

6. The LCRU (or similar equipment) is fairly portable and it is feasible to disassemble it for shipment to and use in amphibious operations. However, it appears more desirable to develop a lighter unit purposely designed to possess the high-degree of portability necessary for amphibious operations.

7. The essential features of the LCRU, i. e., a simple straddle lift towed by a reliable tractor, offer promising avenues for exploitation in current efforts to develop a container-oriented military logistic system. The straddle lift offers two very important (and somewhat inter-related) benefits: (1) low initial investment in RDT&E costs, since so much has already been done with the LCRU straddle lift and other surf cranes; and (2) low fabrication costs because of the simplicity of the structure. Perhaps the biggest cost and time cutting factor is that there is no need to design, test, and build expensive drive trains; instead, motive power will be supplied by a tried and proven rubber-tired or crawler tractor which can be purchased off-the-shelf or obtained from the existing inventory without modification.

Appendix A
SOIL MEASUREMENTS

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SOIL MEASUREMENTS

Penetrometer

Penetrometer readings were taken at the crest of the berm and at the waterline. The standard penetrometer, developed by the Army, was used. The point of the penetrometer is a 30-degree, right-circular cone made of stainless steel. The cone is 1.489 inches high and the base is .798 inches in diameter (giving a base area of .5 square inches). The cone is forced into the sand point first by a shaft of convenient length (usually about three feet). At the other end of the shaft is a proving ring which measures the pounds per square inch applied to the cone base as it is forced downward. A handle on the proving ring is used to manually apply the load. Usually the maximum readings for every three inches of penetration are recorded.

The result of the penetrometer readings are as follows:

Location	Depth	Maximum Reading		
		First Run	Second Run	Average
Top of Berm	0-3"	75	80	78
	3"-6"	160	200	180
Waterline	0-3"	35	50	43
	3"-6"	140	170	155

Grain Size and Density

The density and moisture content of the sand was measured in situ with a nuclear densiometer. In addition, four soil samples were obtained for laboratory testing. Field and laboratory tests were done in accordance with the following ASTM procedures:

Density of In Place Soils by Nuclear
Method
Particle Size Analysis
Soil Classification

ASTM D 2922-71
ASTM D 422-63
ASTM D 2487-69

The results of the field and laboratory tests are presented below and in Figure A-1.

<u>Location</u>	<u>In Place Density (lbs/ft³)</u>	<u>Moisture Content (%)</u>	<u>Unified Soils Classification</u>
Top of berm	99.7	1.4	SP
40' West of berm	101.4	3.0	--

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MECHANICAL ANALYSIS

COBBLES		GRAVEL		SAND		FINES	
COARSE		FINE		COARSE		FINE	

GRAIN SIZE IN MILLIMETERS UNIFIED SOIL CLASSIFICATION SYSTEM

